

# GAS-DISCHARGE DISPLAY APPARATUS

## BACKGROUND OF THE INVENTION

### Field of the Invention

5       The present invention relates to a gas-discharge display apparatus that can display color images.

      A plasma display panel (PDP) that is a typical display device having a screen emitting light by gas discharge is becoming widely available as a wide screen display for a television set after the color display thereof has been  
10       succeeded in commercialization. One of the challenges to improve the image quality of PDPs is to enhance the reproducible color range.

### Description of the prior art

15       As a color display device, an AC type PDP having three-electrode surface discharging structure is commercialized. This type has a pair of main electrodes for sustaining, which are arranged in parallel for each line (row) of the matrix display, and an address electrode for each column.  
20       Division walls for preventing interruption of discharge between cells are provided in stripes. A surface discharging structure includes a substrate on which the pairs of main electrodes are arranged and an opposing substrate on which a fluorescent layer for color display is  
25       arranged, so that deterioration of a fluorescent layer due to an ion impact upon discharge can be reduced to obtain a longer life. The "reflection type" that has the fluorescent layer on the back substrate is superior to the  
30       "transparent type" that has the fluorescent layer on the front substrate concerning light emission efficiency.

In general, Penning gas containing neon (Ne) and a trace of xenon (Xe) (4-5%) is used as a discharging gas. When the discharge between main electrodes occurs, the discharging gas radiates ultraviolet rays, which excite the fluorescent material to emit light. Each pixel includes three cells for red (R), green (G) and blue (B) light colors, and the display color is decided by controlling the light intensity of the fluorescent material of each color. Conventionally, the composition of the fluorescent materials and the ratio of light intensities of three colors are selected so that the display color becomes white when each of the red, green and blue color light intensities is set to the maximum within the variable range.

Concerning the composition of the discharge gas, many studies have been done, a three-component gas (Ne, Xe and He) that is a mixture of the above-mentioned Penning gas and helium, a two-component gas containing helium and xenon (He and Xe), and another three-component gas containing helium, argon and xenon (He, Ar and Xe) are known well.

As explained above, since the fluorescent material emits light by gas discharge in a PDP, the mixing of the light color of the discharge gas into the light color of the fluorescent material cannot be avoided. This causes a problem of deterioration of the color reproducibility.

Fig. 13 shows a light emission spectrum of a two-component gas containing neon and xenon. Fig. 14 is a chromaticity diagram showing influences of the neon light emission on color reproduction.

As shown in Fig. 13, a plurality of light emission spectra appears in the visible light wavelength range

above 580 nanometers. The peak of the light emission of the discharge gas (685 nanometers) is adjacent to the maximum light emission peak (590 nanometers) of the red fluorescent material. Therefore, orange color due to the light emission of the discharge gas is added regardless of the color reproduced by the fluorescent material, so the reddish display occurs over the entire screen. In Fig. 14, the inside of the triangle of the solid line connecting the color coordinates of each fluorescent materials plotted with small rectangles is the reproducible color range when the color of the gas light emission is not added. In Fig. 14, the inside of the triangle of the broken line is the color reproducible range of the PDP measured in a darkroom.

The real color reproducible range is narrowed compared with the original color reproducible range. Especially, reproducibility of blue and green colors is of inferior. Concerning the red color, the reproducibility is not so deteriorated since the wavelength of the gas light emission is approximate to that of the light emission of the fluorescent material. However, focusing the light color of the fluorescent material, the red fluorescent material is different from the ideal red (620 nanometers) defined in the NTSC system. Namely, even if the influence of the gas light emission is little, it is still necessary to improve the color purity of red color. At present, there is no red fluorescent material that emits light of ideal red color and satisfies other use conditions such as efficiency of exciting ultraviolet rays and a life. Green and blue fluorescent materials can emit light of substantially ideal color.

Since the display capacity of blue color is degraded by the gas light emission, the display color of white pixels has a low color temperature compared with the color reproduced by the fluorescent materials of three colors.

5 It is difficult to optimize the relative light intensities of red, green and blue colors in consideration of relative luminosity factor by combining materials because there are few kinds of fluorescent materials that satisfy the use condition at present. Therefore, the color temperature of  
10 the white color is low compared with a CRT even if the color of the gas light emission is not added. Furthermore, if the color of the gas light emission is added, the color temperature drops further. More specifically, the color temperature of the white color display is 5,000-6,000 K  
15 under the condition of the same amplitude signal applied for red, green and blue colors, while the color temperature of a CRT for a TV set in Japan is above 10,000 K. Therefore, it is necessary to raise the color temperature of the white color. However, since the color temperature has different  
20 optimal values depending on the use of the display, the region (the country) where the display is used or other factor, it is preferable that the color temperature can be selected easily within the range of about 6,000-12,000 K.

The color temperature can be raised by weakening the  
25 relative light intensities of green and red colors to blue color. The conventional method for adjusting the color temperature and disadvantages thereof are explained below.

(1) Adjustment by fluorescent material:

There is a method for adjusting the relative light  
30 intensities of red, green and blue colors by selecting the

fluorescent materials, a forming shape thereof or the forming area thereof. This method substantially reduces the brightness of the panel since the light intensities of green and red fluorescent materials are weakened compared with that of blue fluorescent material that is usually lacking in the intensity. Furthermore, there is a limited selection of materials as mentioned above. The adjustment by the forming shape has low reproducibility. If the cell size of blue color is increased to enlarge the forming area thereof, the margin of the voltage to be applied is narrowed and the display becomes unstable since the display characteristics depend on the cell size. In addition, manufacture of panels having different light intensities of the fluorescent material in accordance with the use and the region (country) of use may deteriorate the productivity.

(2) Adjustment by signal:

The intensity balance between the video signals of red, green and blue colors is adjusted. In an example where the level of the video signal is represented by eight bits, i.e., 0-255, the maximum intensities of blue, green and red are represented by 255, 200 and 180, respectively so as to display white color of the maximum intensity. Thus, the color temperature of white color is raised by reducing the amplitude of the input signal of green and red colors compared with that of blue color. This method reduces the brightness of the panel in the same manner as the method (1) mentioned above, and degrades the capacity of gradation display of green and red colors compared with that of blue color that can be displayed in 256 steps of gradation.

Another problem about the color temperature is that

contrast in a well-lighted room is low. The contrast in a well-lighted room (hereinafter, referred to as the bright-room contrast) means a ratio of intensity of light emitted by the fluorescent material and intensity of external light reflected by the PDP. In general, PDPs have a large reflection ratio of external light and a small value of the bright-room contrast. It is clear that the bright-room contrast will be improved by raising the light intensity of the panel and reducing the reflection ratio of external light, but it is not easy to satisfy the compatibility between them. For example, improvement of the filter for EMI measure is considered. Usually, the front surface of the PDP is provided with a filter having transmittance of 40-70% over the entire region of visible light wavelength for protecting interference of electromagnetic field. Though the light emitted inside the panel passes the filter only once, the external light passes the filter twice in both directions. Therefore, the filter improves the bright-room contrast. If the filter having less transmittance is used, the bright-room contrast is further improved. However, since the improvement of the color temperature by the above-mentioned method will reduce the light intensity of the panel, the filter having low transmittance cannot be used for improving the bright-room contrast.

#### SUMMARY OF THE INVENTION

The object of the present invention is to reduce the influence of the light emission of the discharge gas for enlarging the color reproducible range, and to cause the

color purity of red color to approach the ideal value.  
Another object of the present invention is to prevent  
reduction of the color temperature of white color. Still  
another object of the present invention is to raise the  
5 contrast without reducing the display brightness.

In the present invention, an optical filter having a  
size uniformly covering the entire screen is arranged in an  
appropriate position. The optical filter has  
characteristics of selectively absorbing visible light  
10 having a wavelength within the overlapped range of the  
light emission wavelength range of neon or helium and the  
light emission wavelength range of red fluorescent material.

Light within the wavelength range that can deteriorate the  
color reproducibility in the light emitted inside is  
15 selectively absorbed. Since the optical filter makes the  
proper color reproducibility, each of the fluorescent  
materials having different light colors can emit light with  
the maximum intensity in white color, for example. The  
placement of the optical filter covering the entire screen  
20 is much easier than providing a color filter for each light  
color of the fluorescent material.

According to a first aspect of the present invention, a  
gas-discharge display apparatus is provided which utilizes  
at least one of neon and helium gases to generate gas  
25 discharge for exciting three kinds of fluorescent materials  
having different light colors to emit light for displaying a  
color image. The apparatus includes an optical filter that  
is an element overlapping the entire screen, being disposed  
in front of gas discharge space for selectively absorbing  
30 light having wavelength equal to that of light emission of

the gas. The optical filter has characteristics in which the transmittance  $T_{585}$  at the wavelength of 585 nanometers is smaller than the transmittance  $T_{450}$  at the wavelength of 450 nanometers and the transmittance  $T_{620}$  at the  
5 wavelength of 620 nanometers.

In a second aspect of the present invention, the optical filter has characteristics in which the wavelength of peak absorbency in the visible light wavelength range has a value within the range of 550 to 620 nanometers.

10 According to a third aspect of the present invention, the apparatus includes an optical filter that is an element overlapping the entire screen, being disposed in front of gas discharge space for selectively absorbing light having wavelength equal to that of light emission of the gas. The  
15 optical filter has characteristics in which first and second peak absorbencies exist in the visible light wavelength range. The wavelength of the first peak absorbency has a value within the range of 550 to 620 nanometers, and the wavelength of the second peak absorbency has a value within  
20 the range of 500 to 550 nanometers.

In a fourth aspect of the present invention, the optical filter has characteristics in which first and second peak absorbencies exist in the visible light wavelength range, the transmittance  $T_{585}$  at the wavelength of 585  
25 nanometers is smaller than the transmittance  $T_{450}$  at the wavelength of 450 nanometers and the transmittance  $T_{620}$  at the wavelength of 620 nanometers, and the transmittance  $T_{525}$  at the wavelength of 525 nanometers is smaller than the transmittance  $T_{450}$ .

30 In a fifth aspect of the present invention, the



transmittance  $T_{585}$  is smaller than 0.7 times the transmittance  $T_{450}$ .

In a sixth aspect of the present invention, the transmittance  $T_{585}$  is smaller than 0.7 times the transmittance  $T_{450}$  and is smaller than the transmittance  $T_{525}$ .

According to a seventh aspect of the present invention, the apparatus includes an optical filter that is an element overlapping the entire screen, being disposed in front of gas discharge space for selectively absorbing light having wavelength equal to that of light emission of the gas. The optical filter has characteristics in which first and second peak absorbencies exist in the visible light wavelength range. The wavelength of the first peak absorbency has a value within the range of 580 to 600 nanometers. The wavelength of the second peak absorbency has a value within the range of 500 to 550 nanometers. The transmittance of the optical filter at the first peak absorbency is smaller than 0.5 times the average transmittance in the blue wavelength range. The average transmittance in the green wavelength range is larger than the transmittance at the first peak absorbency and is smaller than the average transmittance in the blue wavelength range.

In an eighth aspect of the present invention, the optical filter is made as a component separate from a display device having the gas discharge space, and is disposed in front of the display device.

In a ninth aspect of the present invention, the optical filter is made of a film having said characteristics.

In a tenth aspect of the present invention, the optical

filter is in contact with the front surface of a transparent substrate making up the screen.

In an eleventh aspect of the present invention, the optical filter is made of an organic resin in which a substance absorbing light of a specific wavelength is dispersed.

In a twelfth aspect of the present invention, a non-glare layer is disposed in front of the optical filter.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a structure of a plasma display apparatus according to the present invention.

Figs. 2A and 2B show structures of other plasma display apparatuses.

Fig. 3 is an exploded view of the PDP according to the present invention.

Figs. 4A and 4B show the light emission spectrums of blue and red displays.

Fig. 5 is a chromaticity diagram showing the result of the filter having a peak absorbency wavelength of 590 nanometers in blue color display.

Fig. 6 is a chromaticity diagram showing the result of the filter having a peak absorbency wavelength of 590 nanometers in red color display.

Fig. 7 shows schematically the characteristics of the filter according to the present invention.

Fig. 8 shows the change of color temperature along with absorption of light having the wavelength of 590 nanometers.

Fig. 9 shows a first example of the characteristics of the optical filter.

Fig. 10 is a chromaticity diagram showing the color reproducible range corresponding to the characteristics of Fig. 9.

Fig. 11 shows a second example of the characteristics of the optical filter.

Fig. 12 is a chromaticity diagram showing the color reproducible range corresponding to the characteristic of Fig. 11.

Fig. 13 shows a light emission spectrum of a two-component gas containing neon and xenon.

Fig. 14 is a chromaticity diagram showing influences of the neon light emission to color reproduction.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, the present invention will be explained more in detail with reference to embodiments and drawings.

Fig. 1 shows a structure of a plasma display apparatus 100 according to the present invention.

The plasma display apparatus 100 includes a PDP 1 that is a color display device, a driving unit 80 for lighting cells of the PDP 1 in accordance with display contents, an optical filter 60 having spectrum transparent characteristic unique to the present invention, a front plate 92 for protecting the PDP 1, and an armor cover 90.

The front plate 92 is made up by providing an electromagnetic shield film and an infrared cutting filter onto a substrate that is optically transparent, and applying a surface treatment for non-glare finish. Glass, acrylic resin, polycarbonate, or other materials can be used for making the substrate.

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The optical filter 60 has a dimension covering the entire screen that is a set of cells in the PDP 1, and is in intimate contact with the front surface of the PDP 1. The optical filter 60 can be formed by a process such as  
5 sticking a laminated filter film, sticking a film in which a pigment or a colorant is dispersed, or laminating a multicoated interference film utilizing thin film technology. Such sticking or laminating can be processed to the front surface of the PDP 1 directly, or to the front plate 92 so  
10 as to overlay on the PDP 1. Characteristics of the optical filter 60 and the front plate 92 are uniform over the entire screen.

Fig. 2A and 2B show structures of other plasma display apparatuses, that is a variation of arrangement of the  
15 optical filter.

In the plasma display apparatus 100b shown in Fig. 2A, the optical filter 60 contacts the back surface of the front plate 92 intimately, and is separated from the PDP 1. This configuration has an advantage in that the front plate 92  
20 absorbs an external shock, so that the PDP 1 cannot be broken down easily. In addition, heat sink effect can be expected, i.e., the gap between the PDP 1 and the front plate 92 with the optical filter can be used as an air duct, in which external air or cooling air forced by a cooling  
25 fan can flow so as to prevent the PDP from being heated.

In the plasma display apparatus 100c shown in Fig. 2B, the optical filter 60 contacts the PDP 1 intimately, and the front plate 92 is separated from the optical filter 60 so as to enhance protection effect. The optical filter 60 is  
30 formed by sticking a film, and a non-glare finish is

performed before the sticking, so as to reduce an optical interface by which external light is reflected. The non-glare finish is preferably AG process that makes an image soft and inconspicuous by light diffusion. If AR process is used, regular reflection ratio can be reduced substantially, but an external image can be reflected clearly.

In the above-explained three examples, the optical filter 60 is disposed between the PDP 1 and the front plate 92. However, the optical filter 60 can be disposed in front of the front plate 92. If the optical filter 60 is disposed in front of the light emitting portion of the PDP 1, the optical filter 60 can be formed inside the PDP 1.

Fig. 3 is an exploded view of the PDP according to the present invention.

The PDP 1 has first and second main electrodes X and Y making a pair arranged in parallel for generating a sustaining discharge. In each cell (display element), the main electrodes X, Y and an address electrode A as a third electrode cross to make a three-electrode surface discharge structure. The main electrodes X and Y extend in the row direction of the screen (the horizontal direction), and the second main electrode Y is used as a scan electrode for selecting cells in a row upon addressing. The address electrode A extends in the column direction (the vertical direction), and is used as a data electrode for selecting cells in a column. The area of the substrate where the main electrodes and the address electrodes cross is the display screen.

In the PDP 1, a pair of main electrodes X and Y is arranged in each row on the inner surface of a glass

substrate 11 that is a substrate of a front substrate  
structure 10. The row is a line of cells in the horizontal  
direction of the screen. Each of the main electrodes X and  
Y includes a transparent conductive film 41 and a metal  
5 film (a bus conductor) 42, and is covered with an  
insulating layer 17 having a thickness of approximately 30  
microns made of low-melting glass. The surface of the  
insulating layer 17 is coated with a protection film 18  
made of magnesia (MgO) having a thickness of several  
10 thousands angstroms. The address electrodes A are arranged  
on the inner surface of a glass substrate 21 that is a  
substrate of a rear substrate structure 20, and is covered  
with an insulating layer 24 having a thickness of  
approximately 10 microns. On the insulating layer 24, a  
15 division wall 29 having a shape like a band of height 150  
microns viewed from the top is disposed at each space  
between the neighboring address electrodes. These division  
walls 29 divide the discharging space 30 in the row  
direction into plural subpixel (plural unit lighting  
20 regions), and define the gap size of the discharging space  
30. In addition, red fluorescent material 28R, green  
fluorescent material 28G and blue fluorescent material 28B  
for color display are arranged coating the inner surface of  
the rear side including the upper portion of the address  
25 electrode A and the side surface of the division wall 29,  
so that the three colors are arranged in a periodic pattern.  
The fluorescent materials 28R, 28G and 28B are selected so  
that white color is reproduced when each of them emits light  
in the maximum intensity, and the forming shapes of them  
30 are the same. A preferred example of the fluorescent

materials is shown in TABLE 1.

TABLE 1 PREFERRED FLUORESCENT MATERIALS

5	Light Emission Color	Fluorescent Material
	Red	(Y, Gd)BO <sub>3</sub> : Eu
	Green	Zn <sub>2</sub> SiO <sub>4</sub> : Mn
	Blue	BaMgAl <sub>19</sub> O <sub>17</sub> : Eu

10

The discharging space 30 is filled with a discharging gas containing neon as a base and xenon (4-5%), and each color of the fluorescent materials 28R, 28G and 28B is partially excited by ultraviolet rays emitted by xenon upon discharging so as to emit light. In the plasma display apparatus 100 according to the present invention, a color balance of red, green and blue colors can be adjusted by designing the characteristics of the optical filter 60.

Therefore, it is not required to select the fluorescent materials severely or to adjust the forming shape of the fluorescent material of each color for optimizing the color balance.

One element of display (a pixel) includes three subpixels having different light colors arranged in the row direction. The structure of each subpixel is the cell. Since the division walls 29 are arranged in a stripe pattern, the portion of the discharging space 30 corresponding to each column is continuous over all rows. An electrode gap between neighboring rows is set to a value substantially

larger than the surface discharge gap (e.g., 80-140 microns), which can prevent discharge connection in the column direction, e.g. a value within a range of 400-500 microns. The address discharge is generated between the main electrode Y and the address electrode A of a cell to be lightened (in the case of write address format) or a cell to be not lightened (in the case of erase address format), so that a charged state is formed in each row where only the cells to be lightened have an appropriate quantity of wall discharge. Then, a sustaining voltage  $V_s$  is applied between the main electrodes X and Y, so that the cells to be lightened can generate surface discharge.

Hereinafter, characteristics of the optical filter 60 will be explained. In the following explanation, Ne-Xe (4%) Penning gas is used as the discharging gas, which emits light having the spectrum shown in Fig. 13. However, any gas containing helium (He) or krypton (Kr) can be used as the discharging gas regardless of whether neon is contained or not. Helium and krypton emit light having a wavelength in the range of 580 ~ 600 nanometers in the same way as neon, so the optical filter 60 of the present invention having wavelength selecting property is effective.

Figs. 4A and 4B show the light emission spectrums of blue and red displays.

As shown in Fig. 4A, the light emission spectrum, in which only the blue fluorescent material 28B is excited to emit light, includes a light emission spectrum of the fluorescent material in the wavelength range of 400-550 nanometers, as well as a light emission spectrum of neon in the wavelength range above 580 nanometers. If this light



emission above 580 nanometers can be eliminated by the filter, purity of blue color will be improved. However, as shown in Fig. 4B, the light emission spectrum of the red fluorescent material 28R has substantially three peaks at wavelengths of 595 nanometers, 610 nanometers and 625 nanometers, and the distribution range is substantially overlapped with that of the light emission spectrum of neon.

Therefore, the filter that eliminates entire light emission spectrum of neon also eliminates the light emission of red color, and causes substantial deterioration of intensity of red display.

The inventors have studied about the wavelength range to be eliminated, and obtained the following result. Namely, if the wavelength spectrum of the light emission spectrum in which the product of the light intensity and the relative luminosity factor becomes the maximum, i.e., 585 nanometers and surrounding wavelength spectrum is eliminated, the purities of blue and green colors can be improved with suppressing the deterioration of red color intensity at the minimum. In addition, the spectrum of red light emission approaches the monochrome light emission of 620 nanometers that is the ideal in NTSC standard.

Fig. 5 is a chromaticity diagram showing the result of the filter having a peak absorbency wavelength of 590 nanometers in blue color display. Fig. 6 is a chromaticity diagram showing the result of the filter having a peak absorbency wavelength of 590 nanometers in red color display. Here, an imaginary filter having an ideal absorbency characteristics as shown in Fig. 7 is supposed for studying about the relationship between the

transmittance T and the chromaticity at the peak absorbency.

As shown in Fig. 5, the chromaticity of blue color is improved and approaches the ideal value (NTSC standard) when the transmittance at the peak absorbency decreases.

5 In the same way for red color, as shown in Fig. 6, the chromaticity approaches the ideal value along with the transmittance being decreased.

10 The improvement of the color temperature will be explained next. As explained above, if a filter that absorbs light having wavelength around 590 nanometers is provided, the light intensity of red color decreases and the coordinate of the white color on the chromaticity diagram moves in the direction in which the x value decreases. In other words, the color temperature increases  
15 as the arrow in Fig. 8 shows. It is desirable that the chromaticity coordinate in white color be on the blackbody radiation curve shown by the thick line in the figure. However, if the light intensity of only red color is attenuated, deviation from the blackbody radiation in the Y-axis direction increases along with the increase of the  
20 attenuation. When the chromaticity coordinate shifts in the direction that Y value increases from the blackbody radiation curve, white color becomes greeny white. When the chromaticity coordinate shifts in the direction that Y value decreases, white color becomes containing a little  
25 purple. Neither change of white color is desirable. In order to solve this problem, the filter preferably has a characteristic having peak absorbency in the green color wavelength range, too. The transmittance of the filter is  
30 set so that the light intensity of the green color decreases

to the extent corresponding to the decrease of red color,  
 so that the chromaticity coordinate of the white color can  
 be corrected to be a coordinate on the blackbody radiation  
 curve. Such adjustment of color temperature, though it  
 5 causes decrease of light intensity due to transparency of  
 the filter, has advantages in that the bright-room contrast  
 is improved in contrast to the adjustment of the signal  
 amplitude that is adopted in the conventional technique,  
 and in that the optimal color temperature can be realized  
 10 easily in accordance with the use only by changing the  
 filter characteristic. The reason why the bright-room  
 contrast is improved is as follows.

When  $L_0$  is light intensity ratio at the front surface  
 of the PDP 1,  $T$  is transmittance of the optical filter 60,  $S$   
 15 is illumination of external light at the front surface of  
 the optical filter 60, and  $R$  is diffuse reflection ratio at  
 the front surface of the PDP 1, a contrast ratio can be  
 derived from the following equation.

20 CONTRAST RATIO = (LIGHT INTENSITY AFTER PASSING THE  
 FILTER) / (REFLECTION INTENSITY OF EXTERNAL LIGHT)

$$= (L_0 \times T + S / \pi \times R \times T^2) / (S / \pi \times R \times T^2)$$

$$= (L_0 + S / \pi \times R \times T) / (S / \pi \times R \times T)$$

$$= L_0 / (S / \pi \times R \times T) + 1$$

Supposing that  $R$  and  $S$  are constants, the larger  $L_0$  is or  
 25 the smaller  $T$  is, the larger the contrast ratio becomes.  
 The improvement of the color purity and the adjustment of  
 the color temperature according to the present invention do  
 not reduce the light intensity  $L_0$  since the adjustment of  
 fluorescent material, the cell structure, and the signal  
 30 amplitude. In addition, the improvement of the color

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purity and the adjustment of the color temperature are achieved by reducing the transmittance  $T$ , so that the bright room contrast is improved.

Fig. 9 shows a first example of the characteristics of the optical filter 60. In Fig. 9, the transparency is shown by a thick solid line and the light emission spectrum of the fluorescent material is shown by a thin solid line for a reference.

As shown in Fig. 9, the peak absorbency wavelength in the visible light wavelength range is 590 nanometers, a value within the range of 550-620 nanometers. The transmittance  $T_{585}$  at the wavelength of 585 nanometers is smaller than both the transmittance  $T_{450}$  at the wavelength of 450 nanometers and the transmittance  $T_{620}$  at the wavelength of 620 nanometers.

Such characteristics are obtained by forming a pigment layer that can absorb light of the wavelength 585 nanometers on a polyethylene film having thickness of 200 microns. As the pigment, 1-Ethyl-4-[(1-ethyl-4(1H)-quinolinylidene)methyl]quinolinium iodide whose peak absorbency (Absorption Maximum) is 590 nanometers (KABUSIKIGAISHA NIPPON KANKOUSHIKISO KENKYUUSHO Product Number NK-6), and 3-Ethyl-2-[3-(1-ethyl-4(1H)-quinolinylidene)-1-propenyl]benzoxazolium iodide whose peak absorbency is 594 nanometers (KABUSIKIGAISHA NIPPON KANKOUSHIKISO KENKYUUSHO Product Number NK-741) can be used. By adjusting the quantity of additives of these and other pigments, desired characteristics can be achieved. Though it is ideal for selectively absorbing light emitted by the discharging gas that the peak absorbency wavelength of the filter is

identical to the gas light emission wavelength, some beneficial result can be obtained if the peak absorbency is in the range of approximately 550-620 nanometers. However, if the difference between the peak absorbency wavelength and the gas light emission wavelength is large, the absorbency wavelength range should be widened, resulting in increase of filter color. Therefore, the appropriate value of the peak absorbency wavelength is in the range of 580~600 nanometers.

Fig. 10 is a chromaticity diagram showing the color reproducible range corresponding to the characteristics of Fig. 9. The color reproducible range connecting the chromaticity points of red, green and blue colors without the optical filter 60 is shown by the triangle in the broken line, and the chromaticity coordinate of white color is shown by the black dot. The color reproducible range with the optical filter 60 is shown by the triangle in the solid line, and the chromaticity coordinate of white color is shown by the x mark.

It is understood that the color reproducible range is enlarged in all ranges of red, green and blue colors, and the chromaticity coordinate of the white color is reduced both in X and Y (i.e., the color temperature is raised). The color temperature is raised from 5,000 K to 7,000 K. However, the chromaticity coordinate of white color is a little shifted upward from the blackbody radiation curve shown in the solid line to be greeny white color.

Fig. 11 shows a second example of the characteristics of the optical filter 60. In Fig. 11, the transparency is shown by a thick solid line and the light emission spectrum

of the fluorescent material is shown by a thin solid line for a reference.

In the characteristics of Fig. 11, an absorbency is added whose peak wavelength is close to the wavelength of 525 nanometers that is a light emission peak wavelength of the green color fluorescent material 28G so as to solve the problem of the color temperature in the characteristics of Fig. 9. Namely, a first peak absorbency wavelength is a value within the range of 550-620 nanometers (585 nanometers), and a second peak absorbency wavelength is a value within the range of 500-550 nanometers (525 nanometers). The transmittance  $T_{585}$  at the wavelength of 585 nanometers is smaller than both the transmittance  $T_{450}$  at the wavelength of 450 nanometers and the transmittance  $T_{620}$  at the wavelength of 620 nanometers. In addition, the transmittance  $T_{525}$  at the wavelength of 525 nanometers is smaller than the transmittance  $T_{450}$ . Particularly, the transmittance  $T_{525}$  is smaller than 0.7 times the transmittance  $T_{450}$  and is smaller than 0.5 times the average transmittance in the blue color wavelength range (distributed light emission of blue color fluorescent material).

Fig. 12 is a chromaticity diagram showing the color reproducible range corresponding to the characteristics of Fig. 11. In Fig. 12, the color reproducible range connecting the chromaticity points of red, green and blue colors without the optical filter 60 is shown by the triangle in the broken line, and the chromaticity coordinate of white color is shown by the black dot. The color reproducible range in the state with the optical filter 60

is shown by the triangle in the solid line, and the chromaticity coordinate of white color is shown by the x mark.

It is understood that the color reproducible range is enlarged in all ranges of red, green and blue colors, and the chromaticity coordinate of the white color is reduced both in X and Y (i.e., the color temperature is raised). The color temperature is raised from 5,000 K to 7,000 K. In addition, the chromaticity coordinate of white color is on the blackbody radiation curve, to be ideal coordinate. Furthermore, the bright-room contrast when the illumination of the PDP 1 at the front surface is 300lx is further improved from 20:1 to 40:1 by the arrangement of the optical filter 60 having the characteristics shown in Fig. 11.

The color temperature can be adjusted to any value within the range of 5,000-13,000 K by controlling the spectrum transparent characteristic of the optical filter 60. More specifically, if the absorption quantity around 590 nanometers in Fig. 11 is increased so that the transmittance becomes less than 10%, a color temperature above 10,000 K can be achieved and the same performance as a CRT for TV set can be realized. If the absorption quantity around 590 nanometers is decreased to that the transmittance becomes approximately 50%, a color temperature about 6,500 K can be achieved and the same performance a CRT for publishing or designing use or a CRT for a TV set used in Europe can be realized. Namely, a display apparatus having the optimum color reproducibility for use and area (country) can be provided by changing the spectrum transparent characteristic

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of the optical filter 60 without changing the material and the structure of the PDP 1, so that cost reduction of the apparatus can be realized.

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